Deposition investigation in straw fired boilers

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Introduction

In Denmark straw has been applied as fuel at small combined power and district heating plants since the late 1980's. New equipment have been developed to handle and burn the straw. However, straw is by no means a trivial fuel, problems like fluctuations, deposition in the furnace, corrosion and a poor burn out have been observed at boiler plants. One of the problems has been, the large differences in the amount of deposition in the furnace chamber and on superheater tubes when applying different fuel parcels. Knowledge of how to characterize the straw for predicting the deposition properties in the boiler is needed. We will here present deposition experiments performed at two straw fired power plants with a fuel input of respectively 18 and 30 MW.

Some limited experiments have earlier been performed on smaller scale boilers[1,2], no clear correlation between laboratory analyses of the straw and deposition in the boilers was found. Combustion experiments on a combined wood and straw fired 18 MW stoker fired boiler have been performed[3]. Strong indications, of condensation of the mineral matter at different places in the boiler chamber, were seen.

Serial straw has typically a high content of potassium (0.5-1.3%), chloride (0.2-0.7%) and silicium (0.3-1.0%)[4]. KCl sublimates at typical combustion conditions and equilibrium calculations indicate that most of the potassium is in the gas phase at 900 °C[6]. The equilibrium calculations also indicate that a high Cl to K ratio gives a higher amount of K in the gas phase. The low melting point for some potassium species gives a high risk of the formation of hard deposits on furnace walls and convection tubes. A component as KCl melt at 771 °C, and KCl can contribute to melt formation at even lower temperatures when combined with other components as in deposits. Also the system K_2O - SiO_2 has a minimum melting point at 742 °C (68% SiO_2 and 32% K_2O).

Experiments

We have performed 12 one day experiments at full load at two straw fired power plants in the towns Haslev and Slagelse. At both places the straw was received in the form of Hesston bales. Other aspects than deposition were investigated during the experiments, however, this presentation contains only work concerning the deposition properties of the straw.

Haslev: A sketch of the boiler is shown in Figure 1. The bales are continuous fed in four rows into the four burners, where the combustion takes place on the surface of the front bales. The full load fuel input was around 5500 Kg/h corresponding to 18 MW.

Slagelse: (see Figure 2) The bales are reamed and the straw are fed by 9 screws into a moving grate boiler. The full load fuel input was around 7400 Kg/h corresponding to 30 MW.

Table 1 shows the 12 straw types that were applied for the experiments. Wheat, barley and rape were used with water contents of 11 to 16 %, chloride contents of 0.06 to 0.95 % (dry matter) and a potassium contents of 0.28 to 1.97 % (dry matter).

The experimental programme included air cooled deposition probes (around 1.8 meter long and with a diameter of 38 mm) inserted near the superheaters and in the boiler chamber. The deposition probes were kept as near at 510°C as possible by the air cooling system. The fouling removal system, normally applied at the plants, in the form of the sootblowing and ionbal cleaning systems, was stopped during the experiments. After one experiment the deposition probes were withdrawn and the deposition was removed from the probes, the first fraction by a brush (loose deposit) and the second fraction by a steel brush and a knife (hard deposit). At the same position, as the deposition probes, temperature and the gaseous alkali content was measured. During all the experiments the operating conditions were monitored and the flue gas emissions were measured (HCl, CO, TOC, CO_2, O_2, NO_x and SO_2). Gaseous alkali measurements are in the developmental phase, and the results will be reported separately.

Aerosol samples were collected in the upstream of the fly ash filter. The aerosol size distribution was studied by a low-pressure cascade impactor and a scanning mobility particle seizer. It was possible to study particles from 0.01 to 2 micron.

In experiment 1 and 2 at Haslev and experiment 1,3,6,7 and 8 at Slagelse the amount of fed straw and the generated fly and bottom ash, was also measured. Detailed chemical analyses of straw, ash and deposits were performed.

Results

With respect to deposition wheat and barley were seen to behave reasonably similar, while rape was markedly different. The rape straw has a higher sulfur and calcium content but a much lower silicium content. In the following wheat and barley are discussed simultaneously while the experiment with rape is not included.

A very high amount of submicron aerosols was generated in the boilers. The mean diameter of the particles was around 0.3 micron. The particles consisted mainly of K, Cl and S. A large fraction of the alkaline in the fuel evaporate during the combustion and condensate as aerosols later in the furnace chamber. Figure 3 shows that a close correlation exists between the mass loading of submicron aerosols and the potassium contents of the straw. A detailed discussion of the aerosol formation mechanisms is given in reference 5.

In agreement with the aerosol measurements the fly ash is compared with the straw ash enriched with potassium, chloride and sulfur (see Table 2). The bottom ash has a slightly decrease in the same elements compared with the straw ash.

Table 3 shows chemical analyses of straw ash, bottom ash, fly ash and deposits from experiment 6 at Slagelse. A piece of loose deposits was analyzed with an environmental scanning electron microscope (ESEM) coupled with energy dispersive x-ray spectroscopy. The ESEM gave results as the proportion between the elements. In the table the elements are prescribed to give a total of 65%. The ESEM analysis gives information about the layer a few micron deep into the sample. Table 3 shows that compared with the fly ash the deposits are rich in silicium, this is probably caused by impaction of larger particles on the probe. This was not the case for all the experiments. The hard deposit of experiment 6 has a much higher chlorine to potassium ratio than the loose deposit. This was also observed in most of the other experiments. The ESEM analysis of the inner and the outer side of the deposit is reasonably similar and dominated strongly by potassium and chlorine. The surfaces are probably dominated by elements from the aerosols or from condensation of vapors.

During experiment number 6 two probes were inserted into the furnace chamber. Deposits at the extra probe were removed at different time intervals to study the dependency of residence time (see Table 4). It is seen that the total flux of deposition was reasonable independent of time while the fraction of hard deposit increased with the time.

The total deposition flux on the probes has been related to the potassium content in the straw. Figure 4 shows the results at the superheaters and Figure 5 the results in the furnace chamber. Similar to the aerosol generation a reasonable correlation with the water soluble potassium content in the straw is seen.

Figure 6 shows the flux of hard deposit in the furnace as a function of the chlorine content in the straw. A better correlation between the chlorine content of the straw and the hard deposits was seen than between the potassium content and the amount of hard deposits. With an increasing chloride content, the Cl to K ratio is also higher, this leads probably to condensation at a lower temperature (shown by equilibrium calculations in reference 6). With less potassium condensed prior to the probe, more potassium condensate directly on the probe surface. Also a high KCl content of the deposit gives a lowering of the deposit melting temperature.

Figure 7 shows the amount of hard deposits at the superheaters. Here, the picture is less clear. Because the temperature is lower the amount of hard deposits is lower and the
measuring error much higher. Looking at Figure 6 and 7 it is seen that an increase in local temperature and in straw chlorine content gives an increase in the amount of hard deposit.

One experiment was performed with Rape straw. Large amounts of isolating deposits were generated in a short time and the temperature in the boiler increased fast. The experiment had to be stopped after 4 hours because of problems with the ash removal system.

Conclusion

It is the first time that such detailed measurements on straw fired boilers have been performed. Deposition formation on surfaces in the boiler can occur by different mechanisms: Condensation, impaction and termoforesis[7]. We think that if the deposition has been partly melted, or if it is generated to a high degree by condensation the deposition is harder and will be more troublesome for the boiler operators.

No correlation could be seen between the traditional laboratory generated ash softening and melting temperatures and the deposition in the boilers.

The results of the experiments with respect to deposition could be summarized in the following points:

- Large amounts of potassium evaporate and later condensate as aerosols.
- A high content of water soluble potassium gives a higher amount of total deposition.
- The local amount of hard deposits on convective surfaces is dependent on whether the alkaline condense as aerosols or directly on the boiler surfaces.
- Increasing local gas temperature gives a higher amount of hard deposits.
- A high chloride content of the straw gives a higher tendency for the formation of hard deposits.

References

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Tables

Table 1. Straw applied for the 8 hour experiments.

Experiment	Straw type	Water content %	Cloride % of dry straw	Potassium (water soluble) % of dry straw
Has1	Wheat	15.1	0.29	0.57
Has2	Wheat	13.5	0.52	1.27
Has3	Barley	12.0	0.56	1.93
Has4	Wheat	14.6	0.44	1.01
Sla1	Wheat	15.0	0.06	0.28
Sla2	Wheat	13.3	0.20	0.74
Sla3	Barley	11.6	0.32	1.36
Sla4	Barley	13.6	0.95	1.97
Sla5	Wheat	13.9	0.51	1.07
Sla6	Wheat	13.2	0.86	1.50
Sla7	Wheat	16.1	0.14	0.48
Sla8	Rape	14.0	0.33	1.40

Table 2. Mean mineral composition (experiments 1 and 2 at Haslev and 1,3,6 and 7 at Slagelse) of Straw ash, bottom ash and fly ash.

Elements (dry sample)	Si	Al	Fe	Ca	Mg	Na	K	S	P	Cl	Sum
Mean in straw ash %	23.67	0.36	0.28	7.72	0.98	0.41	21.59	1.93	0.99	6.78	64.70
Mean in flyash %	7.12	0.17	0.45	2.74	0.42	0.43	37.36	3.21	0.75	22.44	75.09
Mean in bottum ash %	24.22	0.53	0.38	7.64	1.22	0.62	18.26	0.27	1.15	4.89	59.18

Straw ash were generated at 550C

Table 3. Mineral composition for experiment 6 at Slagelse of traw ash, bottom ash, fly ash, the furnace deposition probe and the inner and outer side of deposits (by ESEM).

Elements (dry sample)	Si	Al	Fe	Ca	Mg	Na	K	S	P	Cl	Sum
straw ash %	24.30	0.07	0.10	5.65	0.84	0.13	29.06	1.59	0.96	11.90	74.60
Fly ash %	2.15	0.11	0.28	1.22	0.16	0.57	50.64	3.12	0.65	33.00	91.90
Bottum ash %	28.03	0.30	0.26	7.86	1.33	0.26	17.43	0.14	1.18	0.73	57.53
Hard deposit %	10.28	0.11	2.52	4.07	0.60	0.15	32.38	1.96	1.09	19.00	72.16
lose deposit %	19.16	0.21	0.29	6.43	0.96	0.22	24.08	3.77	1.31	5.40	61.83
ESEM inner side, %	1.24	0.05	0.18	0.72	0.04	0.23	30.75	1.53	0.18	30.09	65.01
ESEM outer side, %	5.56	0.09	0.22	5.77	0.29	0.11	29.37	2.93	1.46	19.20	65.00

Table 4: Experiment 6 at Slagelse: Deposition in the furnace as a function of residence time.

Time the probe were inserted h	0.33	0.66	1.33	2.67	7.17
Total deposit flux g/m2/h	96.1	64.2	69.2	59.6	67.4
Hard deposit flux g/m2/h	1.99	0.76	1.12	10.1	41.96

Figures

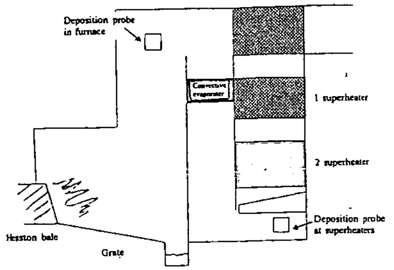

Fig. 1. Haslev straw fired boiler.

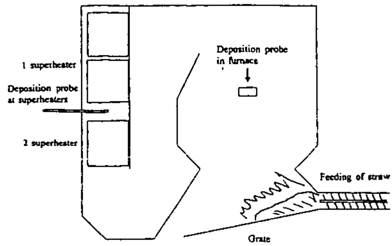

Fig. 2. Slagelse Straw fired boiler.

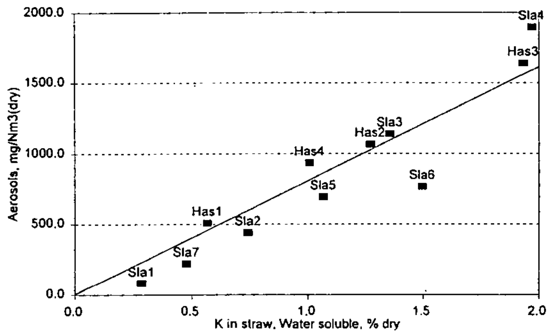

Fig. 3. Total aerosols (0.01 to 2 micron) in the flue gas as a function of water soluble K in the straw.

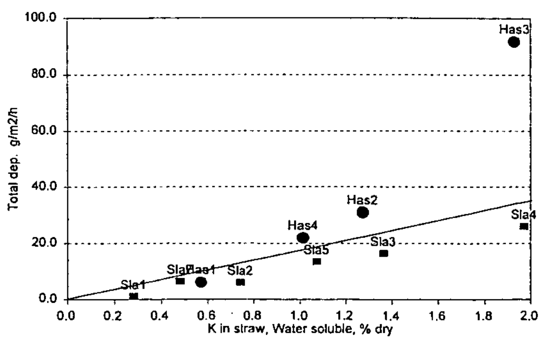

Fig 4. Total deposition flux at the superheaters as a function of water soluble K in the straw.

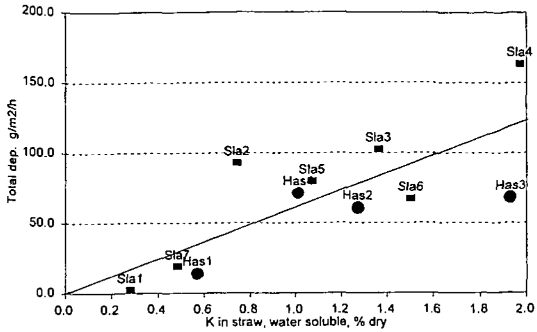

Fig. 5. Total deposition flux in the furnace as a function of water soluble K in the straw.

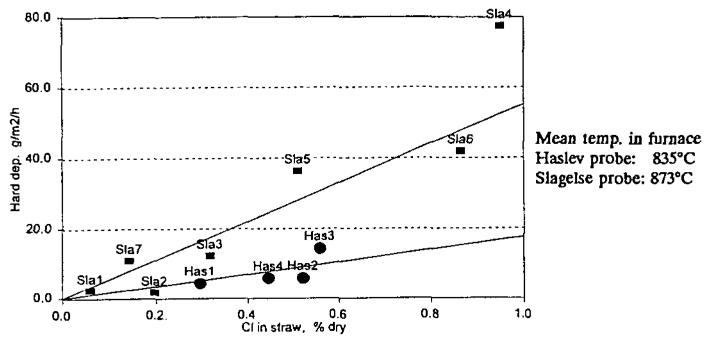

Fig. 6. Deposition flux of hard material in the furnace as a function of Cl in the straw.

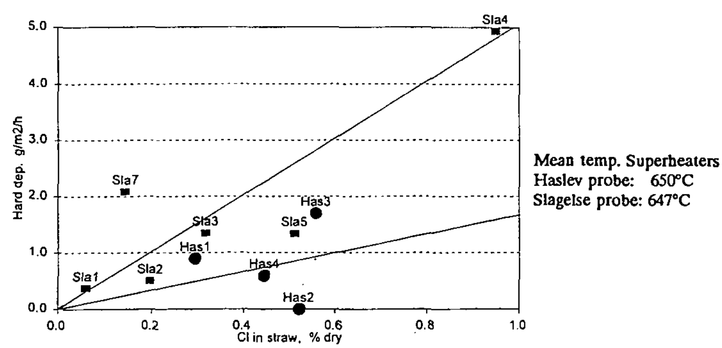

Fig. 7. Deposition flux of hard material at the superheaters as a function of Cl in the straw.